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THE EFFECTS OF TEXTURE ON DISTANCE ESTIMATION IN SYNTHETIC ENVIRONMENTS

by

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EXECUTIVE SUMMARY

Virtual environments offer a safe and cost-effective way to expose people to situations that are inaccessible, dangerous, or simply too costly to otherwise expose them to an actual work environment. As such, their use is highly desirable for many types of training operations. Despite these advantages, one problem with training in a virtual environment is the poor transfer of spatial information from the virtual environment to the real world (Witmer, Bailey, Knerr, & Parsons, 1996; Bliss, Tidwell & Guest, 1997; Waller, Hunt and Knapp, 1998; Darken & Banker, 1998). If virtual environments are to be useful for high-risk training scenarios, this "spatial transfer" problem must be overcome.

One possible contributing cause of this training transfer problem may be due to poor distance perception that typically accompanies immersion in a virtual environment. Numerous studies have found that observers significantly underestimate egocentric distance judgements while immersed in a virtual environment (Witmer & Kline, 1998; Witmer & Sadowski, 1998; Henry & Furness, 1997; James, & Caird, 1995; Lampton, McDonald, & Singer, 1995). Egocentric distance is the distance from the observer to some object or location in the environment. Real world studies reveal that the personal ("egocentric") distances are also underestimated (compressed) in the depth plane when verbal report measures are used (Gilinsky, 1951; Harway, 1963). This experimental methodology requires observers to verbally report their distance estimation to some object. An example is magnitude estimations where the observer gives some number to reflect their estimation of the distance observed. This compression of distance in the depth plane is even more pronounced when exocentric distances are measured, where intervals in the depth plane are seen as half the distance of the same interval in the frontal

plane (Haber, 1985; Wagner, 1985). An exocentric distance is the distance between two external objects or locations in the environment. The difference between egocentric and exocentric distances is that egocentric distances are relative to an observer and exocentric distances are not. When egocentric distances are estimated using a visually directed action task such as blindwalking, distance estimations are highly accurate (Thomson, 1983; Steenius & Goodale, 1988; Reiser, Ashmead, Talor, & Youngquist, 1990; Loomis, Fujita, Da Silva, & Fukusima, 1992). Visually directed tasks are an indirect method of determining an observer's perception of distance. They involve having the observer perform some action that requires his or her knowledge of the distance, but does not involve making a verbal response. Thus, rather than giving a number to estimate the observed distance, the observer actually closes his or her eyes and walks to the location. This task is termed blindwalking and accuracy of the observer requires his or her knowledge of the true distance, but it does not require his or her verbalizing of the distance.

Several studies have directly compared distance estimations made in the real world with estimations made in a virtual environment using both verbal report measures and visually directed actions. These studies found distance estimations were significantly shorter in the virtual world compared to the real world, for both a verbal report magnitude estimation task (Witmer & Kline, 1998; Lampton et al., 1995), and for a blindwalking task (Witmer & Sadowski, 1998). An underestimation of distance in a virtual environment likely distorts the large-scale spatial representation of that space, which in turn may limit the degree to which the large-scale spatial information gained in a virtual environment transfers to the real world.

The goal of the current study was to examine distance perception in a virtual environment paying particular attention to factors that might explain why past research has found distance estimation inaccurate. This study focused on two possibilities that may account for the inaccurate distance perception found by previous studies. The first possibility was the use of texture, and the second was the method by which distance judgments are made in the virtual environment. Studies in virtual environments have typically failed to show significant effects of texture on distance estimations (James & Caird, 1995; Witmer & Kline, 1998). This is surprising since texture is known to be a strong cue to distance (Gibson, 1986), and the lack of a continuous textured surface has been shown to cause inaccurate distance judgments in the real world (Sinai, Ooi, & Zijiang 1998). The current study will manipulate the texture of the ground surface by comparing high, medium, and low texture density patterns on distance estimations. The task employed will be a perceptual matching task, similar to the one used by Sinai et al. (1998). They found the distance estimates using this task were very similar to estimates using a blindwalking task, in both control and experimental conditions. Therefore, results using this task may be more accurate because it can be considered a visually directed action rather than a verbal report measure.

The current study focused on the role of textural information on distance perception in a virtual environment using a perceptual matching task. Three texture patterns were tested, each with varying degrees of texture density (low, medium, and high relative density). It was hypothesized that distance judgments would be more accurate when subjects were immersed in an environment containing a high textural density pattern, compared to a low textural density pattern. Secondly, it was hypothesized that

the use of the perceptual matching task itself would result in more accurate distance estimations compared to past studies.

Observers were immersed within a virtual environment consisting of a large L-shaped room with a column located down one corridor and a flagpole located down the other. The observer's task was to view the column, then turn 90 degrees to the right to view the other corridor where the flag was positioned. The observer then moved the flag's position (by using the joystick) until the perceived distance between the observer and the flag was to be the same as the distance between the observer and the column. A within-subject design with column size (2 levels), column distance (4 levels), and surface texture (9 levels) was used.

Statistical analysis revealed significant effects for the texture of the ground where the comparison column was located, but not the texture of the ground where the target flag was located. In addition, the size of the column had some effect; however it was not significant. The effect of distance was also significant in that observers were most accurate at the near distances, tended to overestimate the middle distances, and tended to underestimate the far distances. The interaction between texture and distance was also significant. Despite these significant effects, overall results were generally very accurate with average error less than seven percent of distance compared to previous studies that had average errors of over forty percent.

This study found that egocentric distance judgments in a virtual environment are very accurate. The results demonstrate that observers can use visual cues within a virtual environment to accurately estimate distance. Moreover, these results contradict previous findings which found subjects tend to underestimate distances within a virtual environment (Witmer & Kline, 1998; Witmer & Sadowski, 1998; Henry & Furness,

1997; James & Caird, 1995; Lampton et al., 1995). The discrepancy between this study and previous findings may be due to the observer's task. The current study employed a perceptual matching task which in the real world has been shown to achieve similar results as a visually directed action task such as blindwalking (Sinai et al., 1998). Real-world distance perception studies have found that verbal report measures result in underestimated distance judgments, while visually directed action measures result in highly accurate judgments (Gilinsky, 1951; Harway, 1963; Thomson, 1983; Steenius & Goodale, 1988; Reiser et al., 1990; Loomis et al., 1992). Witmer and Sadowski (1998) measured subjects' virtual distance estimates in a visually directed action task while they virtually traversed the environment on a treadmill. Witmer and Sadowski found that subjects' distance estimates in the virtual environment were approximately 15% short of the actual distance compared to an 8% underestimate in the real-world control condition. The treadmill may have introduced some methodological problems as other studies have found that the use of a treadmill does not improve distance judgments (Witmer & Kline, 1998).

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I. INTRODUCTION

A. OVERVIEW

Virtual environments offer a safe and cost-effective way to expose people to situations that are inaccessible, dangerous, or simply too costly to otherwise expose them to an actual work environment. As such, their use is highly desirable for many types of training operations. Despite these advantages, one problem with training in a virtual environment is the poor transfer of spatial information from the virtual environment to the real world (Witmer, Bailey, Knerr, & Parsons, 1996; Bliss, Tidwell & Guest, 1997; Waller, Hunt & Knapp, 1998; Darken & Banker, 1998). If virtual environments are to be useful for high-risk training scenarios, this "spatial transfer" problem must be overcome.

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turn may limit the degree to which the large-scale spatial information gained in a virtual environment transfers to the real world.

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when subjects were immersed in an environment containing a high textural density pattern, compared to a low textural density pattern. Secondly, it was hypothesized that the use of the perceptual matching task itself would result in more accurate distance estimations compared to past studies.

B. BACKGROUND

The use of virtual environments for training military missions is not new. Military aviation has employed simulators in training for the last fifty years. The value of these simulators is currently assessed solely on the estimated cost of flight hours required to perform the same training in the actual aircraft. Little regard is paid to the human issues that affect the transfer of training skills from simulators to aircraft (U.S. Congress, OTA, 1994). More recently, the military has expanded its use of virtual environments for training in other areas ranging from fire fighting aboard ships to docking maneuvers. It is likely the dramatic increase in the use of virtual environments will continue to rise in the future as the sophistication of the virtual environments systems continues to increase and the cost of design and implementation continue to decrease.

Virtual environment is a very general term that involves many different systems, uses, and procedures. The Webster dictionary (Mish, 1994) defines it as "computer generated artificial world in which a person can participate." This broad definition is very suggestive of the wide range of systems and uses that can be considered as being virtual reality. Thus, the use of this term in a concise and specific way is inherently problematic. This problem is compounded by the fact that it is a pan-disciplinary field, including knowledge and skills from psychological, physiological, engineering, mathematical, and computer science fields. With all these different areas of concentration

come variations in vocabulary, each depending upon the background of the author. For example, a common term in virtual reality is "presence", which is essentially the subjective feeling the operator has of being in a remote or synthetic environment. However the precise definition and use of this term has sparked a large debate among investigators (for example see Draper, Kaber, & Usher, 1998).

These differences in vocabulary also generate questions as to what actually is a synthetic environment. In general, there can be considered four types of synthetic environments, which vary depending on the level of immersion and the differences in stimuli for the operator. These systems include teleoperated systems, simulators, virtual environments, and augmented systems.

1. Types of Synthetic Environments

A teleoperator system is one in which the operator is connected to a human-machine interface that is then connected to some sort of robot through a direct linkage, or a digital network. Information about the environment in which the robot operates is sent through sensors to the operator. The robot operates in a real world environment; however the operators themselves can be considered to be immersed in a virtual environment (Durlach & Mavor, 1995). Another example of this type of technology is fiber-optic surgery. The surgeon views the interior of the patient with a fiber-optic camera and remotely operates the instruments based on his perception of the display.

A virtual environment is one that contains a human operator, a human-machine interface, and a computer generated environment. In this context, the terms "virtual-reality" and "virtual environment" are the same. The major difference between a virtual

environment and a teleoperator system is that the operator is working completely within a computer-generated reality. Figure 1 represents the differences between a teleoperated, a virtual environment system, and a system comprised of a normal interactive process. The computer creates all the cues and displays that the operator can see, hear, or respond to (Durlach & Mavor, 1995).

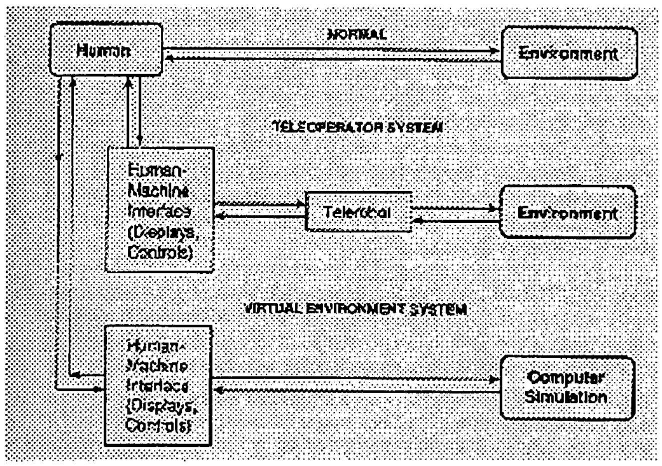

Figure 1 Teleoperator, Virtual Environment, and Normal Systems (Durlach & Mavor, 1995)

A simulator is commonly thought to be a different type of system, though now it is quickly becoming a specific type of virtual environment system. In actuality, a simulator only differs in that the near space (the environment closest to the user) is real rather than computer generated. However, current research aims to make the controls of the simulator, in addition to the scene that the operator sees, computer generated. Simulators are actually the most common types of virtual reality systems. They can vary from the desktop flight simulators to the full-motion, full-scene simulators of military aircraft and some military surface vehicles. The VR-Simulator line blurs a little more with the development of virtual cockpits that display the controls in the synthetic environment.

Augmented reality systems are a blend of virtual environments and teleoperated systems. These systems use a human-machine interface, coupled to some sort of robot device in a real world environment, but the display is a mixture of a sensor display of the real world and computer generated information. The operator could also view a fusion of all three systems, real space, virtual reality, and robotic input. Figure 2 is a diagram of the information flow through an augmented reality system. The operator interacts with all stimuli to guide the robot in real space.

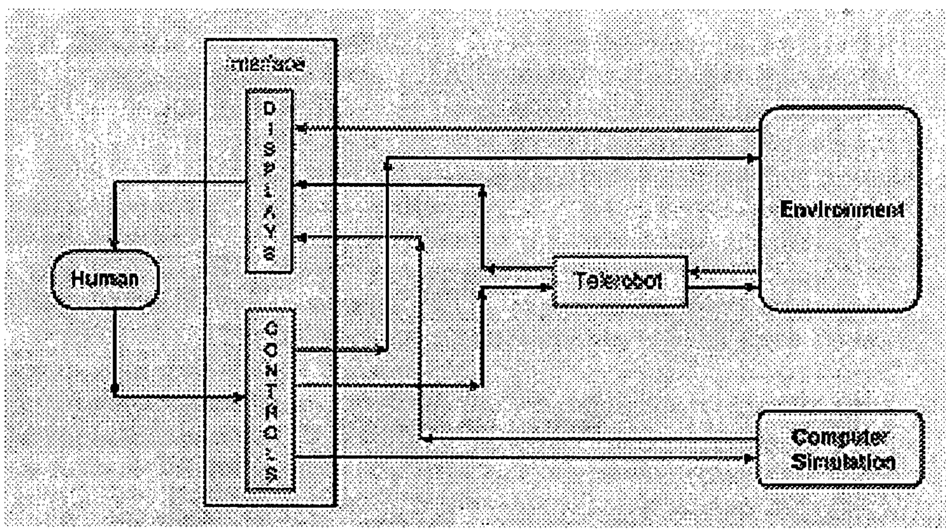

Figure 2 Information Flow in an Augmented Reality System (Durlach & Mavor, 1995)

The collection of all these different types of systems is referred to as "Synthetic Environments (SE)" (Durlach & Mavor, 1995). This covers the entire field, from teleoperator systems, full-dome flight simulators, to three-dimensional "CAVE (see below)" virtual environments. In all of these systems, the operator is projected into a new reality. This reality can be displayed by optics, computer generated, or a mixture of the two. The optical display is the most important part of all these systems. It provides the primary stimulus for all these systems. There are several types of these displays; each with varying levels of detail and expense.

2. Virtual Reality Display Systems

Along with the different types of synthetic environments, there are many ways these environments can be displayed. Four of the more commonly employed display devices are cathode ray tubes, helmet-mounted displays, stereoscopic displays, and CAVE displays.

CRT (Cathode Ray Tube) displays present the user with a flat panel display of the synthetic environment. This display is a standard computer screen-type display. It can generate images in color with high resolution.

Helmet-Mounted Displays (HMD) are worn by the operator covering his or her entire field of view. They can provide a binocular representation of the synthetic environment. They typically consist of two high-performance liquid crystal displays (LCD) screens with special optics to present the scene to the user. They also have a head tracking system that will measure the position of the operator's head. The head's positional information can then be used to update the view of the environment to match the motion of the head. The head tracking system can be an infrared, radio, or magnetic system, among others. Depending upon the requirements of the virtual environment, the HMD's can also be outfitted with a sound system to completely immerse the operator in the environment. Levine and Mourant (1997) conducted a study in shading in virtual environments. They found that helmet-mounted displays give a more compelling view of the virtual scene then standard CRT displays, according to test subjects who were surveyed after the experiment.

Stereoscopic displays are the next generation of CRT displays for synthetic environment systems. They use a well-known phenomenon of presenting two images, just slightly out of phase. By wearing special polarized glasses, the viewer sees the image as if it were in three dimensions. These displays are relatively cheap, compared to HMD's, but they still require large amounts of computer processing power. To correctly present the viewer the correct perspective, some form of head tracking is still needed.

Technology continues to improve stereoscopic displays. The current research is attempting to eliminate three problems. The first is to try to eliminate the necessity of the polarized goggles. This technology is called the autostereoscopic display. The user views a display similar to a normal CRT screen, but can see three-dimensional images. The second problem is the necessity of a head-mounting tracking system on the operator. New methods of tracking the perspective of the user's focus will eliminate the need for a tracking system. The third is the problem of multi-user perspective. Most displays are configured for a single operator. The necessity to share data and information presents a strong case for the development and the usefulness of a multi-user perspective system. There is still a problem of computing power. Instead of generating a view for each of a single user's eyes, the computer has to generate a view for each user's eyes and then another computer must coordinate all the displays, so the correct information is displayed depending on each of the user's view of the scene (U.S. Congress, OTA, 1994).

Combined Audio Video Environments (CAVE) were designed in the Electronic Visualization Laboratory at the University of Illinois at Chicago in 1993. These systems are state of the art for synthetic environment display. The display part consists of three rear-projected stereoscopic displays to provide the operator with 270° of viewing

environment. The use of polarized goggles gives the user the 3-D projected view. The user also has the ability to interact with real objects in the near space. This allows the user to interact with tools that have substance, as well as a virtual projection, without complicated haptic (tactile) interfaces.

The CAVE system also has a complex audio system that allows sound to be projected from any direction inside the CAVE. This can provide the operator additional cues inside the synthetic environment (Cruz-Neira, Leigh, Sandin, & DeFanti, 1993).

Synthetic environments are visually driven. The operator views real space, virtual space, or a combination of the two. The one thing in common with all of them is the necessity of human vision to perceive them. Most problems with virtual reality systems and human performance stem from vision issues, whether the difficulties be in the computer generation of an image for the operator, or with the operator's perception of the representation of the synthetic environment. Problems can range from an inability to interact with the environment, to the extreme, where the interaction with the environment makes the operator physically sick. Some of the specific issues with human vision performance and synthetic environments are lag, field of view, and simulator sickness.

3. Human Performance Issues in VR Systems

Time lag or "lag" deals specifically with the motion of a simulator. It is usually measured by "Transport Delay," which is the time between when the operator creates an input to the system until the system responds. In simulator systems it is usually thought of as the time between when the pilot moves the stick to the time of completion of the update to the screen of video input (Pausch, Crea, & Conway, 1992). Lag may also vary

depending upon the scene detail involved in the environment. As the operator enters an area of high scene detail, the computer generating the environment may have some lag associated with the time required to update the scene (Watson, Spaulding, Walker, & Ribarsky, 1997).

An excessive lag can lead to a decrease in performance in the synthetic environment because the operator will have difficulty adapting to movement within the system. These large lags will lead to overcompensation and result in an operator "chasing" the system to get the correct input (Pausch, Crea, & Conway, 1992). It is thought that lag should be kept between 100-125 ms (Pausch, Crea, & Conway, 1992). Once lag is decreased to this range, it is thought to produce little adverse effect within the simulator and in some areas can even enhance the operator experience. The lag of the visual system influences a simulator's realism more than the depth of the visual scene (Levine & Mourant, 1997).

Field of view (FOV) is a critical element within visual systems. It is an angular measurement of an operator's breadth of vision. It is a common misconception that more is always better when discussing FOV; there is a trade-off between field of view and resolution. Larger FOV's involve larger pixel sizes because the number of pixels generated is limited by the processing power of the computer. In other words there are a fixed number of pixels that can be generated at any given time. However, the size of the individual pixel can be adjusted, depending on the display device. Besides this consideration, there are limits to the performance increases gained by increasing FOV. Haworth, Szoboszlay, Kasper, and Maio conducted a study in 1996 in order to quantify the FOV necessary for acceptable performance. The study was conducted by placing a

helmet that could be adjusted to various fields of view on army helicopter pilots. The pilots' ability to accomplish various flight tasks was measured and evaluated by an instructor. The pilots were also questioned about their performance. The result was that as FOV increased from 49° to 84°, pilot performance significantly increased. The performance increase was measured by a drop in the maneuver error rate, pilot workload, and instructor pilot rating. It was also found that at decreased FOV's, the pilot felt they completed the maneuvers better than the numerical measurements indicated; thus the pilot had a false indication of his or her performance with the decreased field of view. At above 84°, performance continued to increase, but not significantly.

An 84° FOV might not be necessary for all systems. An operator in a system with a relatively static display might not need a HMD with that large a FOV. If the system is not related to flight or dependent upon the operator's perception of motion cues to maneuver in the environment, then an expensive large FOV HMD may not be necessary.

Simulator sickness or cybersickness is most often thought of as a form of motion sickness (Stanney, 1995). It can range from mild discomfort (headache) to more severe symptoms, like vomiting and severe disorientation. It is thought that between 10 and 60 percent of operators experience some form of simulator sickness when using synthetic environments (Kennedy, Lane, Lilenthal, Berbaum, & Hettinger, 1992).

Simulator sickness is not confined to periods when the operator is in the synthetic environment. The symptoms can persist long after the exposure to the environment has ceased (Kennedy, Lane, Lilenthal, Berbaum, & Hettinger, 1992). The U.S. Navy has implemented a mandatory grounding policy following simulation training to avoid pilots experiencing cybersickness while flying.

Simulator sickness is a problem because of the symptoms, but also because it interferes with the training process. Pilots who experience simulator sickness may learn to minimize their movements in order to try to curb the symptoms. This will lead to a counter-productive training situation because pilots will be performing one set of movements for the simulator that would not be appropriate when flying an aircraft. The cost-effectiveness of synthetic environments that induce cybersickness symptoms will decrease, because operators will turn off the features that cause the symptoms or will not use the system (Kennedy, Lane, Lilenthal, Berbaum, & Hettinger, 1992).

All of these performance issues can affect the transfer of training from synthetic environments to real world performance. The problems lie in that it is very difficult to quantify and then eliminate these issues. Thus, further studies of the effects of virtual environments on the human visual system are required.

C. PROBLEM STATEMENT

There are many advantages to developing virtual reality systems to conduct training. Operators can train for hazardous missions without being exposed to the true danger until the mission tasks are perfected. For aviation simulators, the costs are more real. Simulators train pilots on procedures while saving the costs of fuel and maintenance of actually flying the aircraft, and of course, simulator mishaps do not result in the loss of expensive equipment and lives. The same cost-benefit analysis is now being applied to the surface navy, where a virtual reality system is being used to train for replenishing ships at sea. All of these are valid uses of virtual reality, but the inherent limitations of the systems have not been adequately determined.

All training uses of virtual environments depend on the ability of the operator to apply the skills and knowledge gained in the virtual environment to the real world. This concern has prompted investigation into how well that information is transferred. Studies show that while training in a virtual environment can be effective, the transfer of skills and knowledge from a virtual environment to the real world is not perfect, and the results are typically not as good as training in the real world itself (Witmer, Bailey, Knerr, & Parsons, 1996; Tidwell & Guest, 1997; Waller, Hunt & Knapp, 1998). For example Waller et al. (1998) measured an observer's ability to navigate a real world maze and found that training in a virtual environment is not as effective as training in the real world, or even training just with a map. However they did find that prolonged exposure and increased training time in the virtual environment did eventually result in performance as good as performance after training in the real world. These studies show that the transfer of spatial knowledge from the virtual environment to the real world is somewhat limited, which raises concerns about the efficacy of training in a virtual environment.

One aspect of spatial information is distance estimation. Numerous studies have found that observers consistently underestimate distance judgements while immersed in a virtual environment (Witmer & Kline, 1998; Lampton et al., 1995; Witmer & Sadowski, 1998; Allen & Singer, 1997; James & Caird, 1995). An underestimation of distance would likely distort the large-scale spatial representation of the environment, which in turn would limit the degree to which large-scale spatial information gained in the virtual environment would transfer to the real world. Thus, the distortions in distance that are

present in the virtual environment would hamper the use of spatial knowledge gained when observers try to apply that knowledge to the real world.

Many perceptual cues allow humans to judge distances in the real world. One of these that is relevant to virtual environments is ground surface texture (Gibson, 1986). The purpose of the current study was to conduct a human factors experiment, eliminating as many cues to distance as possible, focusing exclusively on texture to determine if ground texture in a virtual environment affects distance estimation. By varying the level of texture from a low-texture environment to a dense texture, distance estimates were expected to improve. Specifically, this study investigated whether the ground surface texture has a significant effect on distance estimation in a synthetic environment. Secondly, this study tested whether distance estimation improved when the ground-surface texture density increased.

II. DISTANCE ESTIMATION IN REAL AND VIRTUAL ENVIRONMENTS

A. PERCEPTUAL CUES

According to Wickens (1992) there are two major categories of perceptual cues in depth perception and distance estimation; object-centered and observer-centered cues. Object-centered cues are those that are a function of the space in which the observer resides. The object-centered cues are linear perspective, interposition, height in the plane, light and shadow, relative size, textural gradient, proximity-luminance covariance, aerial perspective, and relative motion gradient (parallax). The observer-centered cues deal specifically with the operation of the observer's visual system. They are convergence, accommodation, and binocular disparity. All of these cues work in combination to provide the appearance of depth and the ability to estimate distance (Wickens, 1992).

1. Object-Centered Cues

Linear perspective is the perception that when a person looks at a continuing expanse of terrain parallel lines seem to converge (Dember, 1979). The point of convergence of the lines is known as the vanishing point. This phenomenon occurs because even though the lines are parallel, the angle subtended by their separation gets smaller as the distance increases (Sedgwick, 1980). As the orientation of the parallel lines varies on the surface, the location of the vanishing point varies. Groups of parallel lines on the same surface will all have vanishing points on the same horizon.

Interposition is the occlusion of one object by another. The occluded object is assumed to be more distant (Wickens, 1992). Interposition has a strong influence on

relative distance estimation. By varying interposition, the experimenter can make a closer object appear farther than a distant object that occludes it (Dember, 1970). Interposition can only provide information about relative distance. The objects might be at 50 to 100 meters or 5 to 10 centimeters. The effect of interposition does not fade as distance increases. It is as effective at 1 meter as it is at 5000 meters: as long as the objects can be resolved, interposition will give information about which is closer (Cutting & Vishton, 1995).

Height in the visual plane refers to the fact that objects located on the ground that are higher in the visual plane appear farther away (Wickens, 1992). Conversely, objects that are located on the ceiling, for example, are actually nearer to the observer when they are higher in the plane. This distance cue diminishes curvilinearly beyond two meters, so that by about 1000 meters, the strength of the cue decreases to about ten percent. The amount that can be perceived is about 5 minutes of arc between two nearly adjacent objects (Cutting & Vishton, 1995).

Objects lit from one direction will have shadows that offer cues as to their orientation from the observer and some clue as to their shape (Wickens, 1992). An increase in the luminance of an object will make that object appear closer. The position of the sun can negate this effect completely (Cutting & Vishton, 1995). Shadows provide a cue to depth and can provide relative distance information between objects in a visual scene (Dember, 1979).

When two objects are known to be of similar size, the one that subtends the smaller visual angle will appear to be farther from the observer than the one that subtends a larger visual angle (Wickens, 1992). For example, a person that subtends 1 degree of

visual angle will appear to be much farther than a person who subtends 10 degrees of visual angle. If these two people appeared to be at the same distance, one would look like a giant compared to the other. When the sizes of the objects are known, then information about absolute distance can be obtained. However, if the sizes of the objects are unknown, then only relative distance information can be obtained from the relative size cue (Cutting & Vishton, 1995). The effectiveness of this cue does not deteriorate with increasing distance as long as the objects can be accurately resolved.

The textural gradient is the distance cue created by the change in size of the individual textural elements with distance from the observer (Gibson, 1986). The size of the elements decreases with distance and so the grain of the surface will appear finer as the distance from the object increases (Wickens, 1992). The texture on the ground of a visual scene provides a homogeneous scale of reference. The size of objects touching the texture of the visual scene can be inferred by the amount of texture occluded by its projection (Sedgwick, 1980). As might be expected, a symmetric pattern provides more accurate and more consistent information than an irregular pattern (Dember, 1979).

Proximity-luminance covariance is the fact that closer objects appear brighter (Wickens, 1992). The effect is based on the inverse square law, by which illumination intensity is inversely proportional to the square of an object's distance from the light source. Thus the farther the object is, the less illumination will fall on it. (Dember, 1979).

Aerial perspective is the distance cue where objects appear hazier the farther they are from the observer (Wickens, 1992). The effect is due to the composition of moisture and pollutants in the atmosphere that increases the appearance of blue in a scene and decreases contrast (Cutting & Vishton, 1995). This effect increases as the distance from

the visual scene increases and the absence of this effect can lead to vast errors in distance judgement (Dember, 1979). An example of this effect is demonstrated by people misjudging the distance to mountain ranges because the air in mountain ranges is unusually clear (Dember, 1979). As these distant objects become completely indistinct, this cue becomes rapidly ineffective (Cutting and Vishton, 1995), and of course, this cue is ineffective at near distances.

Parallax or relative motion gradient is the distance cue by which objects that are closer to the moving observer travel by the observer faster than objects farther from the observer (Wickens, 1992). This can easily be demonstrated by viewing the scenery outside a side window while travelling in a car. Objects that are near, (poles and signs, for example) move rapidly past the observer. Objects that are distant, (such as trees, hills, and so on) move slowly past the observer. Objects in the far distance, such as the moon, appear to move with the observer (Dember, 1979). It has been shown that relative size can overcome motion information in a visual scene (Dember, 1979).

2. Observer-centered cues

Accommodation is the contraction of the ciliary muscles of the eye to bring a near object into focus on the retina (Dember, 1979). This changes the shape of the lens, making it thicker to increase its refractive strength. Convergence is the rotation of the eyes toward the nose. There are two kinds of convergence; fusional vergence and accommodative vergence. Fusional vergence is the eyes moving toward each other in order to fuse an image into focus on the retina. This is also reinforced by accommodation, which also tends to move the eyes toward each other, hence accommodative vergence (Gillam, 1995). The interoperability (jointness in military terms) of these two ocular

motor cues makes it extremely difficult to measure them independently. The effect on distance estimation from accommodation and convergence depends on the magnitude of the distance you are trying to estimate. It has been found that for distances over 1 meter accommodation and convergence have little effect (Dember, 1979).

Binocular disparity is the distance cue created from the fact that the two eyes receive slightly different views of the world. The observer's perceptual system integrates these two disparate images and forms one complete image (Dember, 1979). This is the basis for the stereoscope and many of the techniques of newer stereoscopic visual displays. Vertical and horizontal disparities can have some effect, though these are not pronounced when they conflict with accommodation and convergence (Gillam, 1995).

Together, these cues provide the distance information necessary for people to accurately perceive distances in the real world. The role of these various cues and the degree to which they contribute to the distance perception likely changes under various circumstances. That is, some cues are more important under some conditions than others. The key for scientists trying to emulate these cues in a virtual environment is to determine which cues can adequately allow the visual system to perceive distances in a virtual environment. For example, are all cues necessary, or are a small subset, or can one single cue provide enough information to observers so that they might perceive distance accurately? These concerns are very important to the designer of virtual environments which are generally considered impoverished environments compared to the real world and where all distance cues may not be able to be accurately reproduced.

B. DISTANCE ESTIMATION IN REAL WORLD STUDIES

The investigation of distance perception has a long history and its study has involved many famous people in history; for example observations on the importance of height in the visual field were made by the Greek mathematician Euclid (Burton, 1945); and an investigation of aerial perspective and relative size was undertaken by Leonardo DaVinci (Taylor, 1960). Other prominent investigators of depth and distance in history include Berkeley (1709) for his work on convergence. The study of distance perception even included one of the founding fathers of modern experimental psychology, Helmholtz, for his study of motion perspective (1867/1925). These famous investigators underscore the ubiquitous nature of distance perception and the pervasive role it plays in our everyday lives.

More recently, the study of distance perception has be taken up in earnest by modern-day psychologists who have attempted to catalogue the various distance cues present in the environment and to define or at least describe their role in distance perception. First of all, it has been shown that in the absence of all distance cues distance perception is severely distorted. Near distances (2-3 meters) are overestimated while farther distances are substantially underestimated (Gogel, 1982; Loomis et al., 1996; Philbeck & Loomis, 1997). These studies compared observers' performance under normal conditions with those in complete darkness, thereby eliminating all distance cues except the visibility of the target itself. Precisely which distance cues were responsible for accurate distance perception could not be determined by these studies, but in any case in the absence of any cues, performance is severely degraded. A study by Sinai, Ooi, and He (1998) found that distance estimations were inaccurate when viewed across a physical

gap placed between the observer and the target. They found observers significantly overestimated the actual distance, providing evidence that distance information is conveyed by the ground surface, and when the ground surface is disrupted then accurate perception of distance is lost.

Studies on distance perception in the real world reveal that an observer's accuracy is dependent on how it is measured as well as what type of distance it is (egocentric or exocentric). Egocentric distance is the distance from the observer to some object or location in space. Exocentric distance is the distance between two external points in space. This distinction is important because studies have found certain characteristics of perceived space for exocentric distances that are not always present for egocentric distances. Studies measuring exocentric distances in the depth interval have found that the distance is compressed, typically as much as 50% compared to distances measured in the fronto-parallel (near-field visual) plane (Wagner, 1985; Haber, 1985; Loomis et al., 1992). This compression of distance in the depth interval for exocentric distances has also been found in studies measuring egocentric distances (Gilinsky, 1951; Da Silva, 1985; Harway, 1963; Toye, 1986). These studies used various types of verbal report measures such as magnitude estimation where distances were given verbally by the subject. These studies suggest that distance is commonly misperceived.

Later studies have found that this inaccurate perception of egocentric distance is not apparent when a different task is used to measure observer's perceived distance. These studies have found that when a visually directed action is used for distance judgments, as opposed to some sort of verbal report measure, observers are generally very accurate at estimating distances (Thomson, 1983; Steenuis & Goodale, 1988;

Loomis et al., 1992; Reiser et al., 1990). A visually directed action means simply that observers do not verbally report the estimated distance to some target, but rather they respond through some action that would indicate where they thought the target was located. For example, a common form of visually directed action is termed "blindwalking". In this task, observers first view a target; then they are blindfolded and walk without visual feedback to the perceived location of the target. Where they stop walking is then taken to indicate where they thought the target was located. Numerous studies have used this technique and found that observers are highly accurate when judging distances in this way (Thomson, 1983; Steenuis & Goodale, 1988; Loomis et al., 1992; Reiser et al., 1990). Another visually directed task is triangulation through pointing (Loomis et al., 1997). In this task, observers first view a target, then close their eyes, point to the target, and walk perpendicularly to the target, finally stopping at some distance. When the observer stops walking, the perceived distance to the target can be calculated by completing a triangle based on the angle of the initial pointing and the angle of the end pointing position. This task also produces accurate distance estimations. Sinai, Ooi, and He (1998) used a variation of this paradigm where they found accurate distance perception could also be shown using a perceptual matching task. This task involves having an observer view some target, and then move the location of a second target to match the distance to the first target. They found similar results between this task and the blindwalking task.

The inaccuracies found by Witmer and Kline (1998) in a virtual environment may have been caused by the verbal report measures that they employed. It is likely that a visually directed task such as that used by Sinai et al. (1998) may reveal more similarities

between distance perception in the real world compared to a virtual world. That is, observers are more accurate when a visually directed action instead of a verbal report is used. It is also interesting to note that Witmer and Kline (1998) did not find any influence of texture on distance perception. This is extremely surprising since texture is a strong cue to distance (Gibson, 1954; Cutting & Vishton, 1995; Sedgwick, 1983). In fact, Sinai et al. (1998) found that when the texture is changed between the target and the observer, the distance estimation is disrupted.

C. DISTANCE PERCEPTION IN SYNTHETIC ENVIRONMENTS

Visual cues for depth perception and distance estimation in the real world are always present for training. Computing power is limited, so the designer of a virtual environment can only add the elements necessary to accomplish training goals. Detailed studies are required to determine which perceptual cues are necessary, and then rank them, so as computing power increases, the cues can be added in a logical order (Hale & Dittmar, 1994).

The current studies have shown mixed results with the effects of texture in distance estimation in virtual environments. One study, Kleiss and Hubbard (1993), dealt with scene detail and the use of texture to compensate for the inability to place a large number of objects in the simulation when it was presented to the subject. They used 24 U.S. Air Force instructor pilots and presented them varying levels of scene detail, object density, and scene texture in three different experiments. Complex textures applied to the global scene were significant in the detection in a change of altitude (Kleiss & Hubbard, 1993). High object density was shown to have more of an effect than texture, but this

may have been due to the lack of terrain contours, where texture might have more of an effect (Kleiss & Hubbard, 1993). They concluded that the optimization of low-level simulators with scenes containing high object .density and texture on terrain surfaces would be more effective for training (Kleiss & Hubbard, 1993).

A second study conducted by Witmer and Kline (1998) attempted to determine the significance of several perceptual cues on distance estimation. Using 24 students from the University of Central Florida, they presented five symmetrical ground surface textures in a virtual environment. Each subject estimated the distance to a black cylinder at varying lengths away from the observation point. They concluded that high-frequency (dense) floor patterns caused observers to over-estimate distance, and low-frequency (less-dense) patterns caused an under-estimation (Witmer & Kline 1998). The results were that the floor texture had no significant effect on estimates of distance (Witmer & Kline 1998). The two studies contradict one another on the value of texture in virtual environments. With strong evidence that texture affects real world distance estimates, more research into its effect in the virtual environment is clearly indicated.

D. SUMMARY

Several studies have directly compared distance estimations made in the real world with estimations made in a virtual environment using both verbal report measures and visually directed actions. These studies found distance estimations were significantly shorter in the virtual world compared to the real world, for both a verbal report magnitude estimation task (Witmer & Kline, 1998), and for a blindwalking task (Witmer & Sadowski, 1998). An underestimation of distance in the virtual environment would likely distort the large scale spatial representation of that space, which in turn would limit the

degree to which large scale spatial information gained in the virtual environment would transfer to the real world. Thus, the distortions in distance that are present in the virtual environment would hamper the use of the spatial knowledge gained when observers try to apply that knowledge to the real world. The goal of the current study is to examine distance perception in a virtual environment and to try to isolate factors that might explain why past research has found distance estimation inaccurate. This study will focus on two possibilities that may account for the failure of past research to show accurate distance perception. The first possibility is the use of texture, and the second is the way in which distance judgments are made in the virtual environment. Studies in virtual environments have consistently shown no effect of texture on distance estimations (Witmer & Kline, 1998; etc). This is surprising since texture is known to be a strong cue to distance, and a lack of a continuous textured surface has been shown to cause inaccurate distance judgments (Sinai et al., 1998). The current study will manipulate the texture of the ground surface by comparing high, medium, and low texture density patterns on distance estimations. The task employed will be a perceptual matching task, similar to the one used by Sinai et al. (1998). The distance estimates using this task were very similar to estimates using a blindwalking task. Therefore, this type of task may find results that are more accurate since it can be considered a visually directed action rather than a verbal report measure.

The current study will focus on the role of textural information on distance perception in a virtual environment. Three texture patterns will be tested, each with varying degrees of texture density (low, medium, and high relative density). It is

hypothesized that distance judgments will be most accurate when subjects are immersed in an environment containing a high-texture density pattern.

III. METHODS

A. SUBJECTS

Ten military personnel from Monterey, CA volunteered for this study. All subjects' vision was reported as normal or corrected to normal. Participants did not report any ocular or visual deficiencies when questioned. All participants signed consent forms prior to testing.

B. APPARATUS

The virtual environment was modeled using Multigen and Vega (Multigen/Paradigm Simulation, Inc.) software packages, and rendered by a Silicon Graphics Onyx Reality Engine. The frame rate was 30 frames/second. Head positions were detected by a Polhemus 3Space Fastrak electromagnetic tracking system with six degrees of freedom. A VR8 HMD manufactured by Virtual Research Systems was used to display the scene. The field of view was 60 degrees diagonal and the resolution was 600 x 480 pixels. Observers manipulated the distance of the comparison object using the joystick and a stop button on a BG Systems Flybox.

C. STIMULUS

The virtual environment consisted of an L-shaped room 60 meters long, 30 meters wide, and 3 meters tall. Two rectangular columns were used as target objects, one with the dimensions 1.5 meters high by .61 x .61 meters wide, and the other with the same dimensions except 1.8 meters high (Figure 3). The comparison object was a flag on the end of a pole, consisting of a cylinder with a radius of .3 meters and a height of 2.4 meters with a red triangle on top (Figure 4).

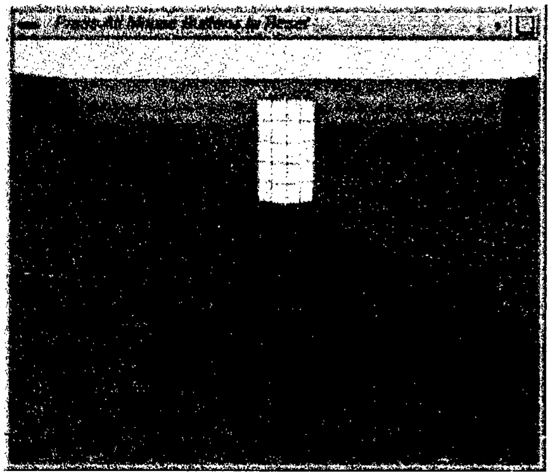

Figure 3 Column Object

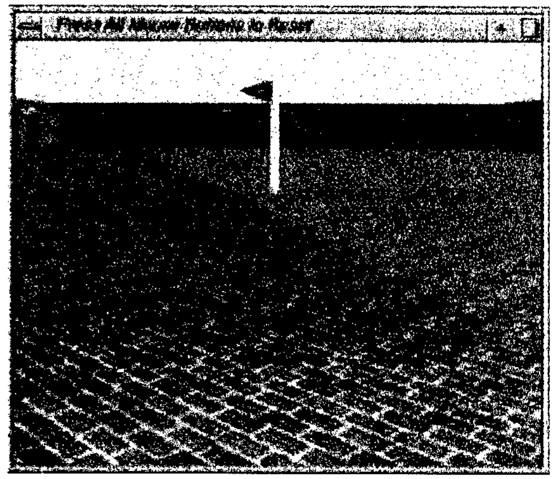

Figure 4 Flag Object

There were three texture patterns used in the experiment. The textures were classified according to their texture density. Texture density was determined by counting the number of texture elements per unit area of texture (Cutting & Vishton, 1995). One was a digitally imaged patch of grass and was considered the high-density texture condition with approximately fifty texture elements per half-foot square (Figure 5). The second texture pattern was a brick pattern and was considered the medium-density texture condition with two or three bricks per half-foot area (Figure 6), and the third texture pattern was a digitally imaged patch of green carpet considered as the low-density condition with essentially no texture elements (Figure 7).

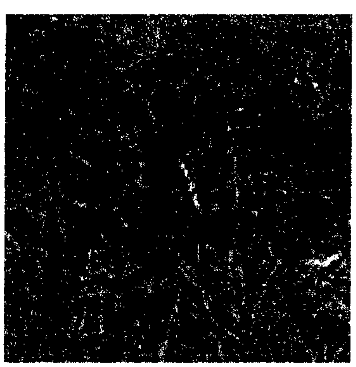

Figure 5 High-Density Grass Texture

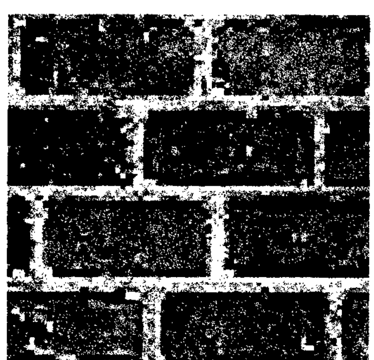

Figure 6 Medium-Density Brick Texture

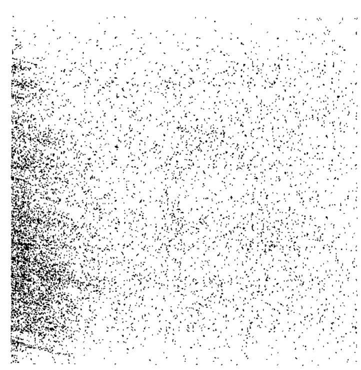

Figure 7 Low-Density Carpet Texture

D. PROCEDURE

The experimental setup was as follows: one test column was placed at some distance down the left side of the L-shaped room. The flag was located at 15 meters distant from the observer down the right side of the L-shaped room. The task for observers was to view the column, turn to face the other corridor of the room (90 degrees), and move the flag's position until the distance between themselves and the flag matched the distance between themselves and the column. Observers were unable to see both the column and the flag at the same time, but they were free to look back and forth as much as they deemed necessary. They controlled the movement of the flag by the joystick on the flybox. They could stop the movement by pressing a button when desired. The observer's position in the virtual environment was always the same, located 15 meters from each wall at the corner of the L. The flag could be moved only along the depth plane. When the observer was satisfied that the flag was at the same distance from them as the column, he or she told the experimenter who then pressed a key on the keyboard which recorded the location of the flag and initiated the next trial.

There were 72 total conditions, and each subject performed each condition once. Four distances were tested: 5, 10, 20, and 30 meters. Two column sizes were used. The texture of the floor was varied independently for each corridor of the room. Thus, for example, the column could be placed on a high-texture pattern while the flag could be placed on the low-texture pattern. Using three textures, there were nine total combinations used in the experiment. Thus the experimental design consisted of 9

texture conditions, 2 column sizes, and 4 distances (9 x 2 x 4). Since every subject participated in every condition, the experiment was a complete within-subject design.

IV. RESULTS

Data was collected in accordance with the above methods from ten subjects. All subjects completed all combinations of treatments resulting in a total of 720 data points. The initial data was plotted with subject estimated distance versus actual distance for each of the texture conditions (Figure 8). The initial graphs indicated that subjects were accurate in all texture conditions.

Subject error was determined by subtracting the true distance from the estimated difference for each trial. The initial analysis was done to assess the normality assumptions for an Analysis of Variance (ANOVA). The initial data was skewed, with heavy tails, and not normally distributed as assumed by the ANOVA process, as shown by the quantile plot (Figure 9). The box-plot indicated that as the distance increased, the variance of the data increased; thus the data was heteroscedastic and standard errors, tests and confidence intervals were untrustworthy (Figure 10).

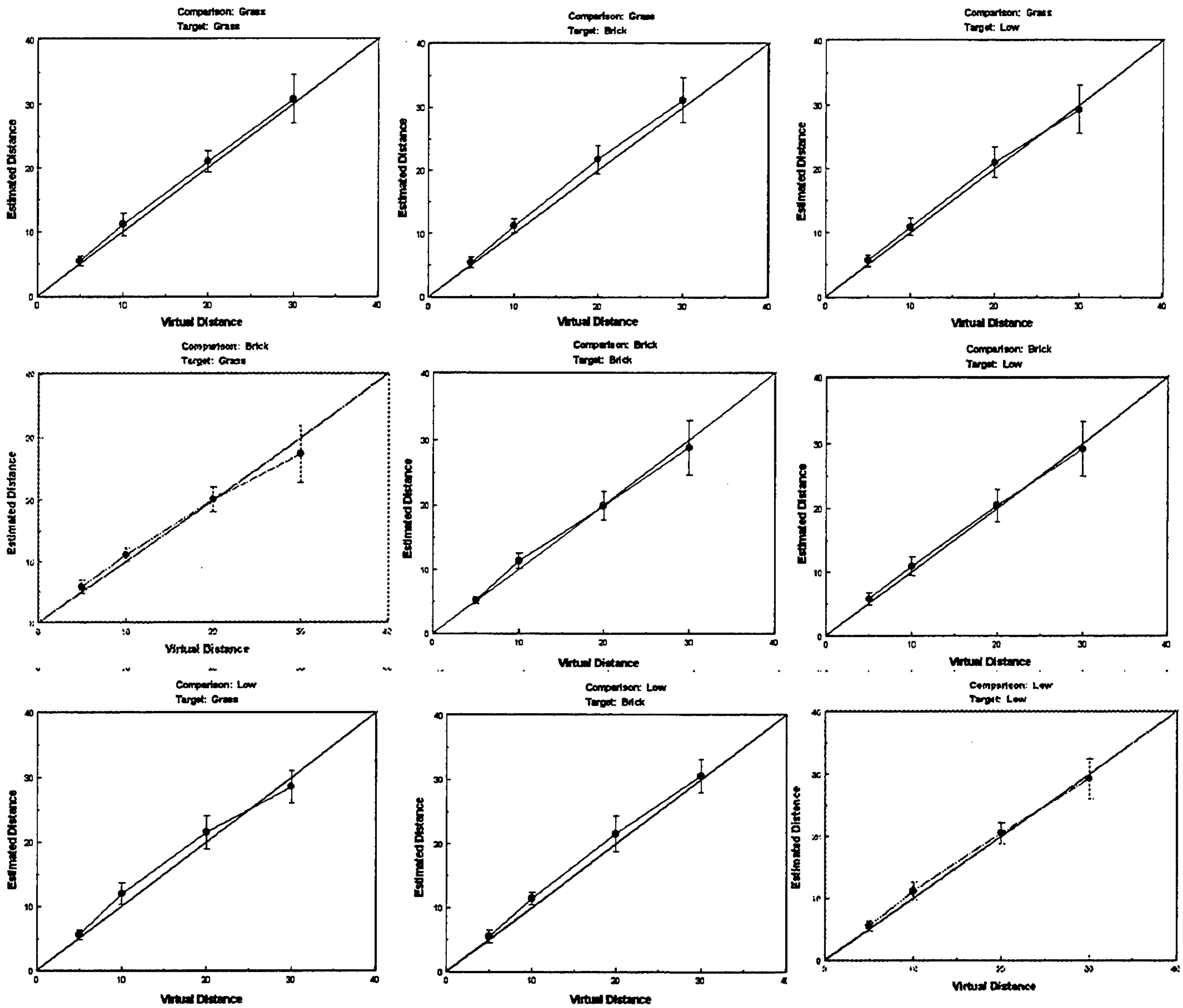

Figure 8 The average results for all ten subjects plotted by distance. The scores for the 2 column sizes were also averaged for this graph. The top three panels show the conditions where the column was located on a high texture region and the flag's texture was varied from left to right being high texture, medium, and finally low on the far right. The middle panels are similarly arranged for when the columns were on the medium texture pattern, and likewise the same for the bottom panels show the data for the low texture condition.

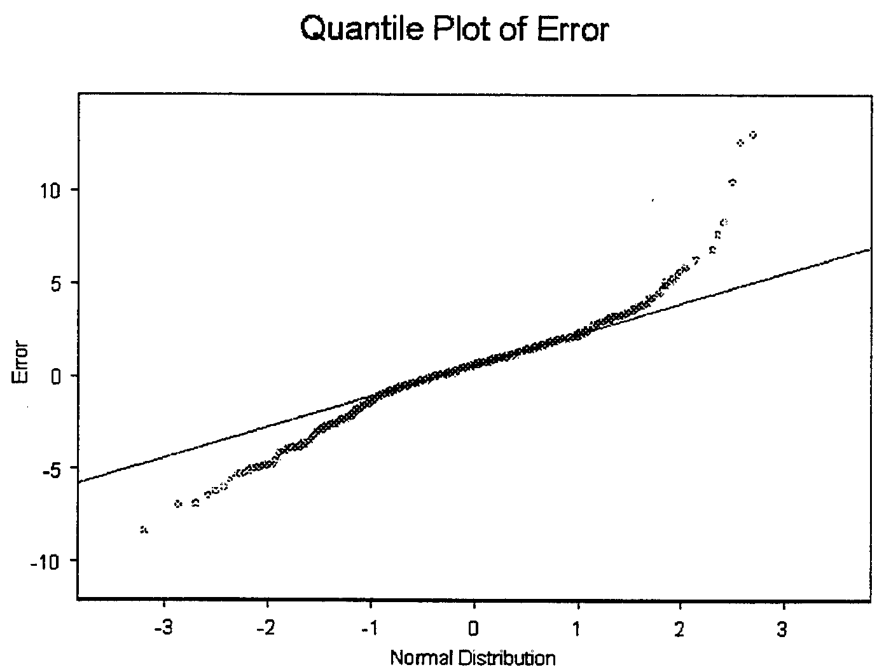

Figure 9 Quantile Plot of Original Data

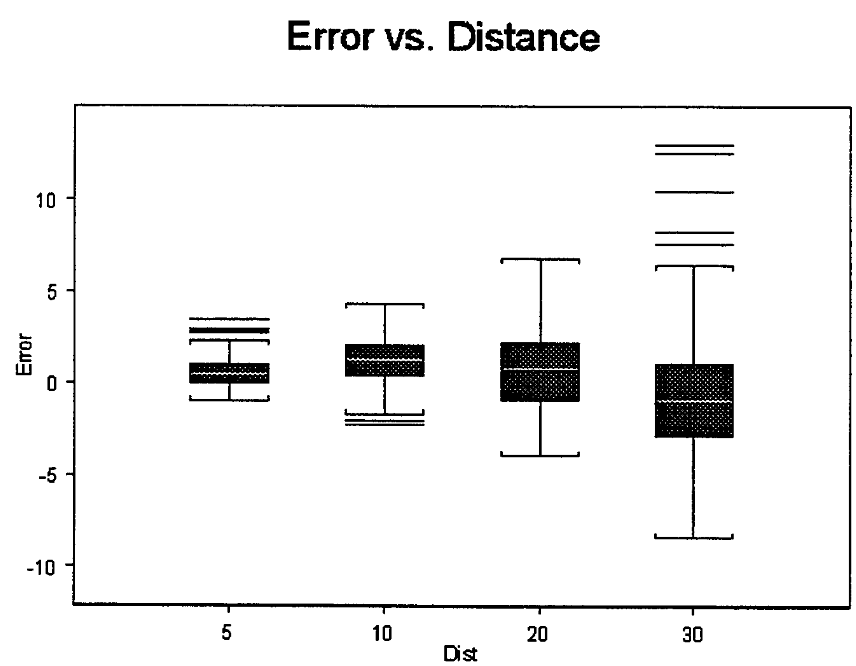

Figure 10 Box Plot of Original Data

To strengthen the normality assumption of ANOVA a transformation of the data was required. Initial attempts at transforming the data by taking the square of the data or taking the square root of the data failed to decrease the variance or reduce the skew of the data appreciably. The logarithm also failed to reduce the variance of the data. The method that reduced skew and decreased variance at each distance was changing each data point into a proportional error for each distance (For example, if a distance was actually 10 meters and the subject estimated twelve meters, the new error was 1.2). The transformation reduced skew and decreased variance at each distance (Figures 11 & 12).

With the more plausible normality assumption of the proportional data, a 9x4x2 within-subject ANOVA was performed to reveal the areas of significance (Table I). The column ground surface texture was significant $\underline{F}(2, 624) = 4.28$, $\underline{p}=0.014$. The effect of distance on estimate error was significant $\underline{F}(3, 624) = 93.8$, $\underline{p}\approx 0$. The other significant effects were the interactions between the column floor texture and distance $\underline{F}(4, 624) = 4.22$, $\underline{p}\approx 0$, between the flag floor texture and distance $\underline{F}(6, 624) = 4.62$, $\underline{p}\approx 0$.

Analysis of Variance Table

Response: NewDist
Terms added sequentially (first to last)

	Df	Sum of Sq	Mean Sq	F Value	Pr(F)
Col	2	0.073	0.0366	4.28	0.014
Flag	2	0.015	0.0076	0.888	0.412
Dist	3	2.404	0.8014	93.8	0.000
Subject	9	3.757	0.4175	48.8	0.000
Col:Flag	4	0.058	0.0146	1.71	0.147
Col:Dist	6	0.217	0.0361	4.22	0.000
Col:Subject	18	0.184	0.0102	1.20	0.256
Flag:Dist	6	0.237	0.0395	4.62	0.000
Flag:Subject	18	0.273	0.0152	1.77	0.025
Dist:Subject	27	2.770	0.1029	12.0	0.000
Residuals	624	5.333	0.0085		

Table I ANOVA of Proportional Error Data

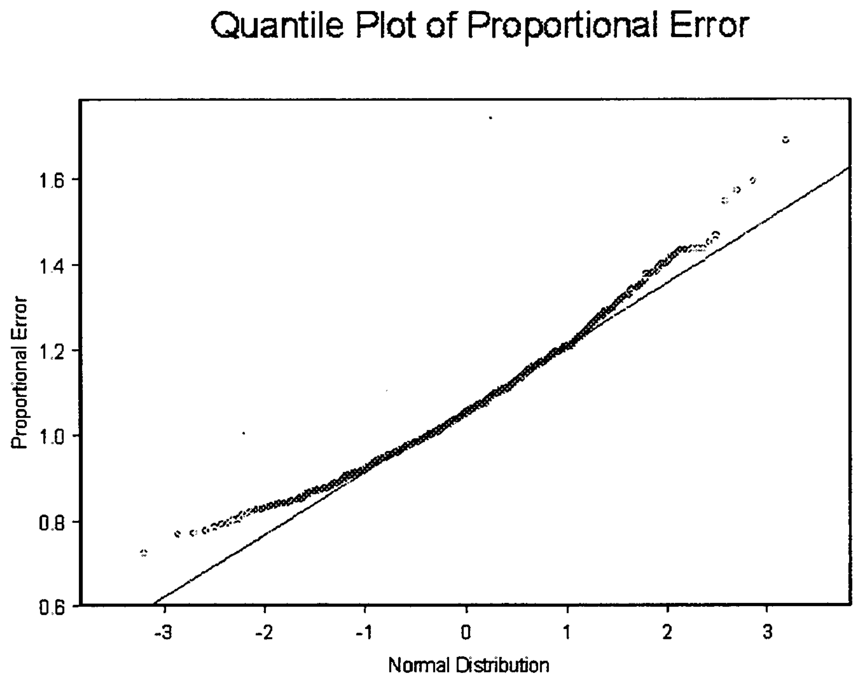

Figure 11 Quantile Plot of Transformed Proportional Data

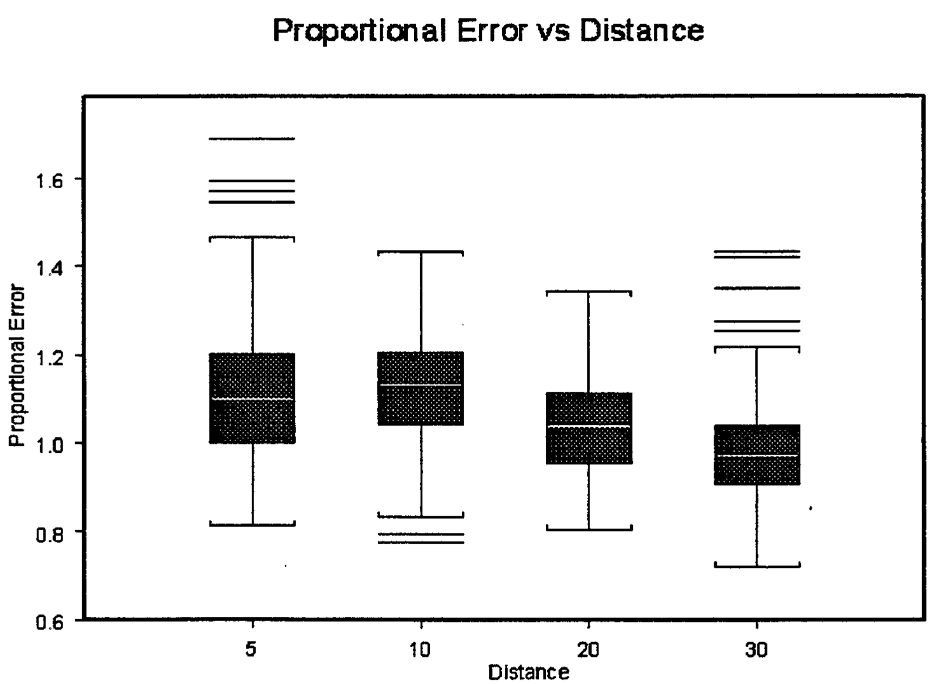

Figure 12 Box Plot of Transformed Proportional Data

Histograms of the proportional data reveal the distribution of errors in the subjects' distance estimation.

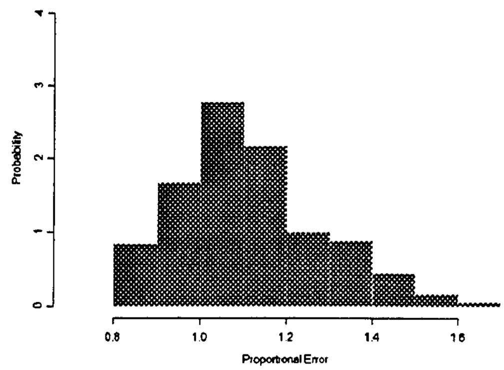

Figure 13 Histogram of Probability Distribution of Proportional Error at 5 Meters

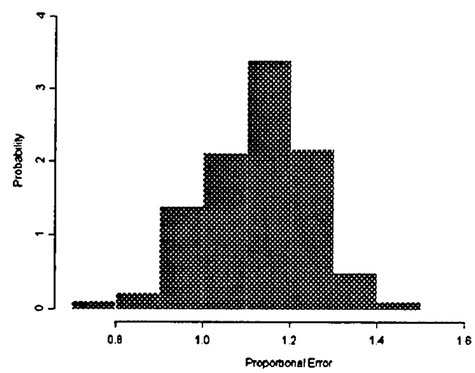

Figure 14 Histogram of Probability Distribution of Proportional Error at 10 Meters

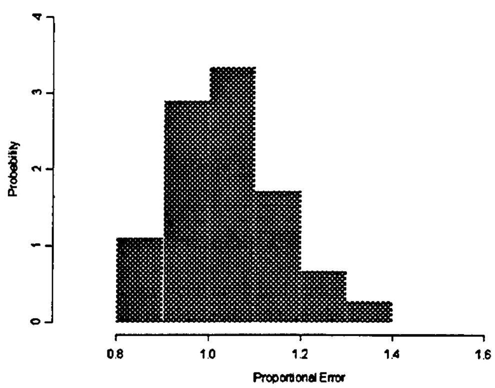

Figure 15 Histogram of Probability Distribution of Proportional Error at 20 Meters

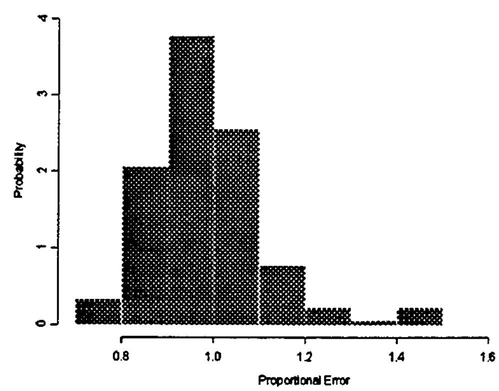

Figure 16 Histogram of Probability Distribution of Proportional Error at 30 Meters

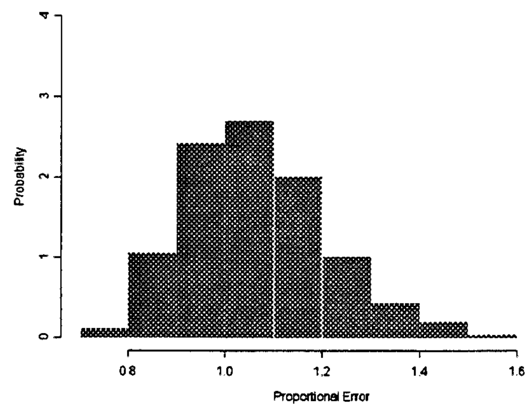

Figure 17 Histogram of Probability Distribution of Proportional Error at all Distances

Many of the subjects overestimated the distance to the target, indicated by the larger amount of probability to the right of 1.0 on the histograms. On average, subjects tended to overestimate about seven percent.

The interaction plot provides the best description of the relationship between the texture of the column and the target flag (Figure 18). The best texture for accurate distance estimations was the brick texture. As long as the target column was on the brick texture, the subject was always better at estimating distances than if he or she started with one of the other two textures. The best estimates were achieved when the target column was on the brick texture and the target flag was on the brick texture. The worst estimates were made when the target column was on the carpet texture and the flag was on the brick texture.

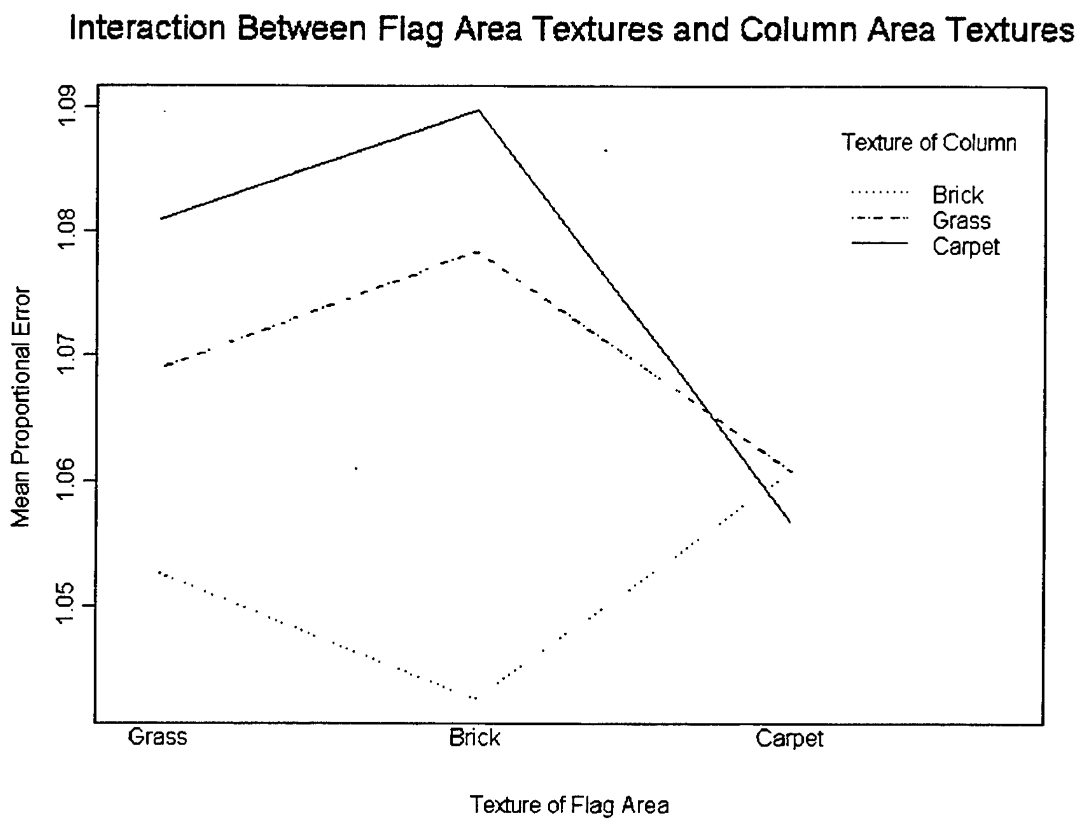

Figure 18 Interaction Plot between Texture Areas

V. CONCLUSIONS

This study found that texture had a significant effect on distance estimations in a virtual environment. This result is contrary to past research, where studies have typically found that texture does not influence distance judgements (Witmer & Kline, 1998; James & Caird, 1995). However, in the James and Caird study, the texture was applied to the walls and ceiling rather than the ground surface. This is important because past studies have demonstrated that ground surface conveys distance information (Sinai et al., 1998; Gibson, 1986). In the Witmer and Kline (1998) study, where texture was applied to the ground, the texture patterns were less dense and more unnatural than the patterns used in the current study.

The current study also found that egocentric distance judgments were reasonably accurate in a virtual environment. Overall, distances were overestimated by around seven percent. Past studies have typically found that distance estimations in a virtual environment were severely underestimated, sometimes by as much as 47% (Witmer & Kline, 1998; Witmer & Sadowski, 1998; Henry & Furness, 1997; James & Caird, 1995; Lampton et al., 1995). It is likely the reason for the discrepancy stems from the nature of the task itself. Past studies typically have used a verbal reporting measure such as magnitude estimation. The current study used a visually directed action measure. A perceptual matching task was used which in the real world has been shown to achieve similar results as a visually directed action task such as blindwalking (Sinai et al., 1998). Only one virtual environment study used a visually directed action task, and that one used a treadmill to simulate walking. In that study (Witmer & Sadowski, 1998) they found distances were only slightly underestimated in the virtual environment compared to their

real world control; 85% of actual distance in the virtual world compared to 92% of the actual distance in the real world. However, it is likely the treadmill introduced some problems as other studies have failed to find benefits of using a treadmill.

The implications of this research are that distance estimates in a virtual environment are more accurate than originally thought. These results suggest that the poor transfer of spatial knowledge in training may be due to the poor textural quality found in early virtual environmental research resulting in poor distance estimation. The reasonably accurate distance estimations and significant effects of texture found in the current study suggest that training could be improved with an increase in texture density.

APPENDIX A. GLOSSARY

accommodation	The dioptric adjustment of the eye to attain clarity of objects of regard at various distances. The inverse of the distance of the object of regard to the eye in meters represents the accommodative stimulus in diopters (Marran and Schor, 1997).
anisometropic error	Differences in accommodative demands between the eyes (Marran and Schor 1997).
biocular	(vision). The same view presented to both eyes (Pausch, Crea, and Conway, 1992).
binocular	(vision) Normal vision, where each eye has a different perspective that allows stereo vision (Pausch, Crea, and Conway, 1992).
contrast	The ratio of the highest luminescence provided by a display to the lowest (Pausch, Crea, and Conway 1992).
diopter	(D). A unit of measurement to designate the refractive power of a lens or optical system and is equal to the reciprocal of the focal length in meters (Marran and Schor 1997).
luminance	The intensity, or brightness of the light coming from a display, measured in candela per square meter (Pausch, Crea, and Conway, 1992).
meter angle	(MA). Represents a unit of convergence. One MA is the angular amount of convergence required for binocular fixation of a point on the median line 1m from each eye's center of rotation. To express other viewing distances in meter angles, one takes the inverse of the viewing distance in meters (Marran and Schor 1997).
myopic error	This is the refractive state of the eye in which the image location of the object being viewed is at some finite point in front of the retina (Marran and Schor, 1997).
resolution	A measurement of the level of detail of a display, measured in pixels per inch. This should not be confused with visual acuity (Pausch, Crea, and Conway, 1992).
vergence	This is the rotational movement of the eyes in opposite directions. It occurs as a response to disparate or unfused binocular stimuli. Convergence is the turning inward of the lines of sight toward each other (Marran and Schor 1997).

visual acuity The clarity of vision. In SE systems, this is limited by the display resolution (Marran and Schor 1997).

APPENDIX B. SOURCE CODE

Equipment:

SGI Onyx with MCO option installed
VR-8 Virtual Research HMD with Polhemus Head Tracker
Polhemus Tracker Receiver
B&G Systems Flybox (Beyond Model 60)
Extra Monitors for Operator Viewing

Hardware Setup:

1) The left (mono) output of the VR-8 must be connected to the video side of channel 0 on the MCO box on the SGI.
2) The Polhemus Tracker on the HMD must be connected to the Polhemus receiver box.
3) The Polhemus receiver box must be connected to tty2 on the SGI.
4) The flybox must be connected to tty3 on the SGI.
5) An extra monitor can be connected to channel 1 on the MCO box to get one channel of the view.
6) Another monitor can be connected to the monitor out on the VR-8 control box to get the same view as the subject.

Software Setup:

1) The following changes must be made to Paradigm Simulation's minimal.c for Vega programming:

This line must be added into the library section of the sample code file.

```
static void getdata(vgWindow *win);
```

This line must added to the sample code before the real time loop of the program.

```
/*windows code for keypress*/
  win=vgGetWin(0);
```

This function must be added to the end of the program, prior to the last close so that it will dump the position data to the command line.

```
getdata(vgWindow *win)
{
  int i;
  vgPosition *pos;
  vgPlayer *play=NULL;
  double x,y,z,h,p,r;

  pos=vgNewPos();
  /* Check if the flagmove Player exsists */
  play=vgFindPlyr("flagmove");
  if(!play)
    {
    printf("vgFindPlyr failed\n");
    vgExit(-1);
    }

  while ((i=vgGetWinKey(win))!=0){

   switch(i){
```

```
      /* Gets the q key to quit the program and output the number to stdio (Screen) */
    case 'q':
     vgGetPos(play,pos);
     vgGetPosVecD(pos,&x,&y,&z,&h,&p,&r);
     printf("%.2f\n",x);
     vgExit(0);
     break;

     default:
      break;
   }
  }
}
```

2) The above program is compiled by issuing the command "make minimal.c" which produces the binary executable program, which can be executed by "minimal *name.adf*", where name.adf is the name of the adf model file generated by Lynx.

3) The successive trials were executed using a shell script, like the one below. This script can be created in any text editor. To get this script to be executable, the unix command "chmod +x+x+x *script.file*", where script.file is the name of the script file created in the text editor.

```
minimal 5lh5.adf >> data
minimal 6nh30.adf >> data
minimal 6lh5.adf >> data
minimal 5nn20.adf >> data
minimal 5nn5.adf >> data
minimal 6ll30.adf >> data
minimal 5nn20.adf >> data
minimal 6ln10.adf >> data
minimal 6hh30.adf >> data
```

4) This script redirects the output to a file called data and then executes the next trial after the q button was pressed. The data file must be renamed between subjects. This can be done by "mv *data subject1.data,*" which moves the data to a new file called subject1.data. The original data file must be removed and this can be done by "rm data."

APPENDIX C. DION EXPERIMENT

The purpose of the following procedure is to allow students to repeat the experiments conducted in this thesis in the Human Systems Integration Laboratory.

1) Turn the power on the VR-8 HMD Black box. (Look for a Red Light.)

2) Turn on the Polhemus FASTRAK Receiver Box. (Look for a Green Light.)

3) Turn on the B&G System Flybox. (Look for the Red Light.)

4) Turn on the two smaller monitors. (Look for the Green Lights.)

5) Log into dion using the account name "3401." No password is required.

6) Open a terminal window by selecting "Desktop", then "Unix Shell".

7) Type "cd Program" to go to the program directory.

8) Type "ls" at anytime to see the contents of the current directory.

9) Type "rndm" to create a subject test file called "hello".

10) Rename "hello" to any other name. In this example the test file name will be subject1. Type "mv hello subject1".

11) To make that file executable so that it can be used to run subjects, you must change the file permissions. This is accomplished by typing "chmod +x+x+x subject1".

12) Log out of the 3401 account by selecting "Desktop", then "Log Out".

13) Log into dion again using the "root" account and the password provide by Professor Krebs.

14) In the terminal window, type "cd /usr/gfx". Then type "hmd". This will shift the graphics to the two smaller monitors and the HMD. If the purple screen comes up, hit "return" twice, otherwise log back into dion with the "3401" account.

15) In a terminal window type "cd program".

16) Have the subject don the HMD. Place their hands on the joystick, and one finger on the button marked "stand".

17) Type "subject1" and the trials will start. The subject will move the flag with the joystick. The button will stop the flag when pressed. Beware the flag has momentum. When the subject has placed the flag at the estimated distance, press "Q" to go to the next trial.

18) When the trials are complete you must rename the data file. Type "mv data subject1.data" to change the name.

19) To reset the display, log out. Then log in as root. Type "cd /usr/gfx", then type "dg". At the purple screen, wait a few seconds and then press "return" twice. At the prompt type "/usr/gfx/startgfx".

20) Turn off all the equipment, especially the HMD.

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